Finite volume approach of natural convection in a triangular enclosure with localized heating from below

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Abstract

In this study, natural convection heat transfer and buoyancy driven flows have been investigated in a right angled triangular enclosure. The heater located on the bottom wall while the inclined wall is colder and the remaining walls are maintained as adiabatic. Governing equations of natural convection are solved through the finite volume approach, in which buoyancy is modeled via the Boussinesq approximation. Effects of different parameters such as Rayleigh number, aspect ratio, prantdl number and heater location are considered. Results show that heat transfer increases when the heater is moved toward the right corner of the enclosure. It is also revealed that increasing the Rayleigh number, increases the strength of free convection regime and consequently increases the value of heat transfer rate. Moreover, larger aspect ratio enclosure has larger Nusselt number value. In order to have better insight, streamline and isotherms are shown.

Keywords: Finite volume, Natural convection, Triangular enclosures.

Introduction

Natural convection heat transfer, which is caused by buoyancy forces and temperature differences in enclosures, have attracted many researches. This phenomenon can be seen in many industrial applications such as cooling of electronic devices, solar energy collectors, design of heat exchangers, heating systems and etc.

Many researchers have investigated convective heat transfer in enclosures with different configurations. Holtzman et al [1], Salmun [2] and Campo [3] made numerical studies on natural convection in triangular enclosures. Chu et al. [4] investigated the effect of heater size and heater location on natural convection in partially heated triangular enclosure. They have found that maximum heat transfer rate will be occurred when the heater is located in the middle of the wall. The effect of Prandtl number on natural convection, in triangular enclosures, in which Aspect ratio is chosen as unity, have been studied by Koca et al[5]. Asan and Namli [6] used finite volume method to investigate the natural convection heat transfer in triangular enclosures, with different inclination angle The effects of aspect ratio of an enclosure have been investigated by Rahman and Sharif [7] Akinsete and Coleman [8] have studied natural convection in an enclosure in steady state regime. Aydin et.al [9] studied natural convection in an inclined square, which is heated from one side and cooled from the adjacent side. They denoted that increasing aspect ratio leads to a reduction in heat transfer rate. Moukalled and Acharya [10] studied natural convection heat transfer inside a trapezoidal shaped enclosure in summerlike and winter like conditions. They found that convection in winter like conditions will dominate at a lower Rayleigh number, in respect with summerlike conditions. Natural convection heat transfer has been analyzed numerically in a triangle enclosure with flush mounted heater on the wall, by Yasin Varol et al [11]. They have examined the effect of Aspect ratio, location of heater, length of heater and Rayleigh number and they have found that among these parameters, position of heater is the most important parameter and can be considered a control parameter. In another study, artificial Neural Network (ANN) and Adaptive-Network-Based Fuzzy Inference System (ANFIS) were used to analyze the natural convection in triangular enclosure which is heated from below. [12] Varol et al [13],Wang [14] and Ridouane [15] have done researches on natural convection in corrugated enclosures using different numerical techniques.

The prime objective of this paper is to analyze the natural convective heat transfer in triangular enclosure which is partially heated from below and to examine the effect of Rayleigh Number, Prantdl Number, Heater location and heater size on the temperature and flow field. In the literature, it is rarely found investigation of enclosure aspect ratio effects and also the effects of bottom wall heater on the temperature and flow field. This study is going to fill this gap.

PHYSICAL MODEL:

The geometric configuration of physical model and the boundary conditions are depicted in Fig 1. The length of bottom wall and height of vertical wall are shown by L and H, respectively. The inclined wall, has constant cold temperature, T_C. A heater with constant hot temperature, T_H, is located in the bottom wall. Remaining walls are under adiabatic condition. The aspect ratio of the enclosure is defined as the ratio of the height of the enclosure to length of bottom wall (AR=H/L).

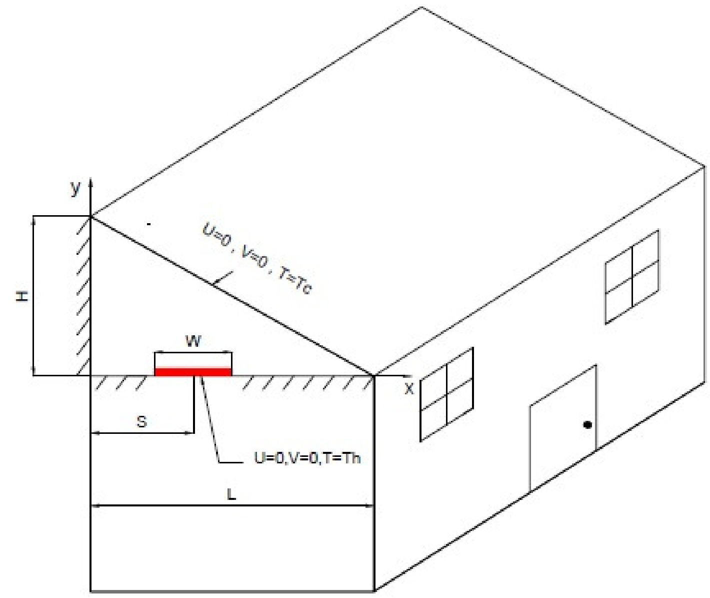

Figure 1. Schematic configuration with boundary conditions

Governing Equations and numerical methods:

The fluid flow is considered laminar, two dimensional, steady, incompressible and Newtonian. It is assumed that radiation heat transfer and viscous energy dissipation are negligible. The variation of fluid properties with temperature is neglected, with the only exception of buoyancy term. The governing equations of natural convection, with Boussinesq approximation, in the non-dimensional stream function velocity form are as follows.

$$-\Omega = \frac{\partial^2\Psi}{\partial X^2} + \frac{\partial^2\Psi}{\partial Y^2} \tag{1}$$

$$\frac{\partial^2\Omega}{\partial X^2} + \frac{\partial^2\Omega}{\partial Y^2} = \frac{1}{Pr}\left(\frac{\partial\Psi}{\partial Y}\frac{\partial\Omega}{\partial X} - \frac{\partial\Psi}{\partial X}\frac{\partial\Omega}{\partial Y}\right) - Ra\left(\frac{\partial\theta}{\partial X}\right) \tag{2}$$

$$\frac{\partial^2\theta}{\partial X^2} + \frac{\partial^2\theta}{\partial Y^2} = \frac{\partial\Psi}{\partial Y}\frac{\partial\theta}{\partial X} - \frac{\partial\Psi}{\partial X}\frac{\partial\theta}{\partial Y} \tag{3}$$

The employed non-dimensional variables are given as :

$$X = \frac{x}{L} \qquad Y = \frac{y}{L} \qquad \Psi = \frac{\psi Pr}{\upsilon} \qquad \Omega = \frac{\omega (L)^2 Pr}{\upsilon} \qquad \theta = \frac{T - T_C}{T_H - T_C}$$

$$u = \frac{\partial\Psi}{\partial y} \qquad v = -\frac{\partial\Psi}{\partial x} \qquad \omega = \left(\frac{\partial v}{\partial x} - \frac{\partial u}{\partial y}\right) \qquad Pr = \frac{\upsilon}{\alpha} \qquad Ra = \frac{\beta g (T_H - T_C) L^3 Pr}{\upsilon^2}$$

The boundary conditions of the physical model are as follows. In this model, u and v velocities are considered to be zero.

The heater on the bottom wall	$T = T_H$
Insulated part of bottom wall	$\frac{\partial T}{\partial n} = 0$
Vertical wall	$\frac{\partial T}{\partial n} = 0$
Inclined wall	$T = T_c$

In the present study, finite-volume method is used as a numerical procedure to solve the governing equations. To obtain grid independent solution, some grid tests are performed between 20×20 and 180×180 The value of Nusselt number is used as a sensitivity measurement. The tests show that 100×100 is the optimum grid dimension. The computational results of present study are compared with the results of Asan and Namli [16] and Tzeng et al.[17] for validation. As, it can be seen in Fig. 2, the computed results of the present study are in a very good agreement with literature

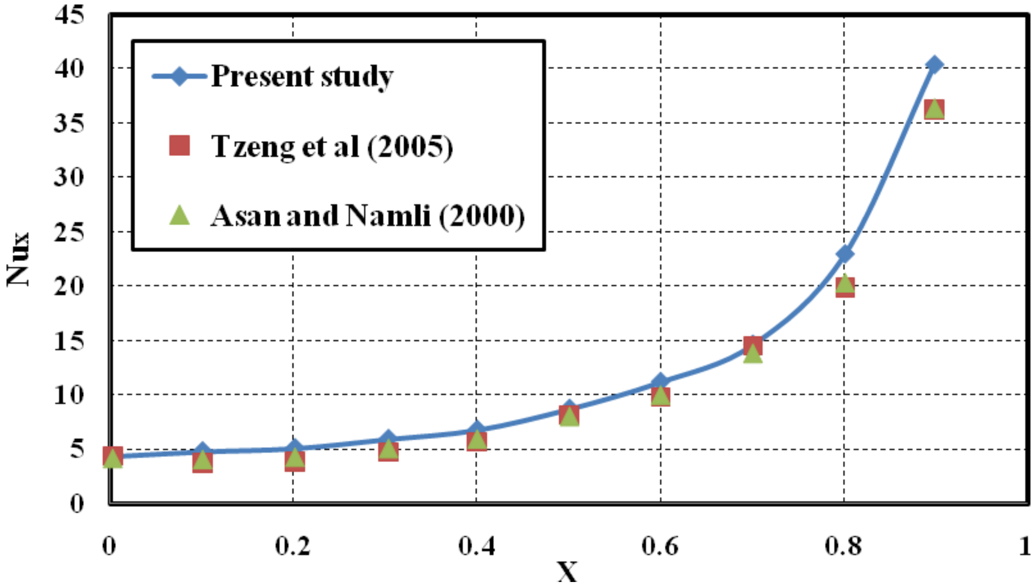

Figure 2. Comparison of local Nusselt number with literature

Result and discussions:

Numerical analysis of natural convection in triangular enclosure is conducted to study the influence of different parameters including Rayleigh number, Length and Position of the heater and aspect ratio on flow field and temperature distribution. The influence of parameters on natural convection heat transfer is presented by means of Nusselt number of the heater, located on the bottom wall.

The fluid, which is in the vicinity of bottom wall and heater is hotter and consequently has lower density with respect to the fluid which is near the inclined wall and this will cause recirculation of the fluid flow and natural convection. It is clear that, by increasing the Rayleigh number, Ra heat transfer rate increases due to increasing the strength of convection regime and increase in temperature difference among cold and hot walls. Streamlines and isotherms for different Pr are plotted in Fig 3. It can be seen that changing the Prantdl number have profound effects on flow field and temperature distribution. Strong plume like distribution forms at low Pr numbers. Thicker thermal boundary layer is obtained with higher Pr number. When Pr=15, the main cell elongates through the bottom wall of the enclosure.

The variation of mean Nusselt number with Ra for different Pr is presented in Fig. 4. It can be seen from this figure that, increasing Pr will give rise to an increase in the mean Nusselt number due to a change in a heat transfer mode. In another words, more free convection cells are created and cause heat transfer increment. Fig. 5 shows the variation of mean Nusselt number of heater with Rayleigh number, for different location of the heater. It is implied that by moving the heater toward the inclined wall, the Nusselt number increases due to smaller distance between cold and hot wall. The effect of heater length on natural convection is investigated and the results are depicted in Fig. 6. It is observed that heat transfer enhances by increasing the length of the heater, due to bigger heat transfer surface. Increment of heater size reinforces the free convection and the heater has effect on higher fraction of fluid. As presented in Fig. 7, increasing the AR leads to a reduction in heat transfer rate, due to an increase in volume of enclosure and the distance between hot and cold walls.

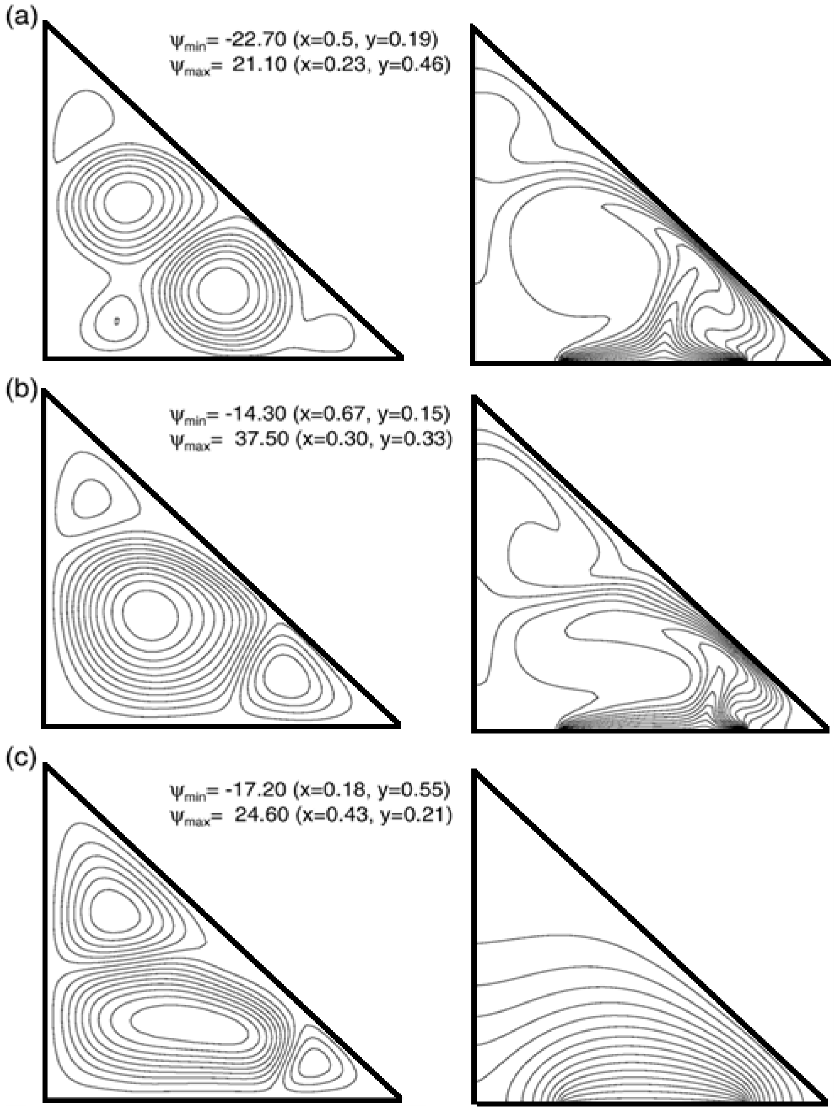

Figure 3: Streamlines (on the left) and isotherms (on the right) at w=0.5, s=0.5, AR=1.0, Ra=10^5, a) Pr=0.01, b) Pr=1, c) Pr=15.

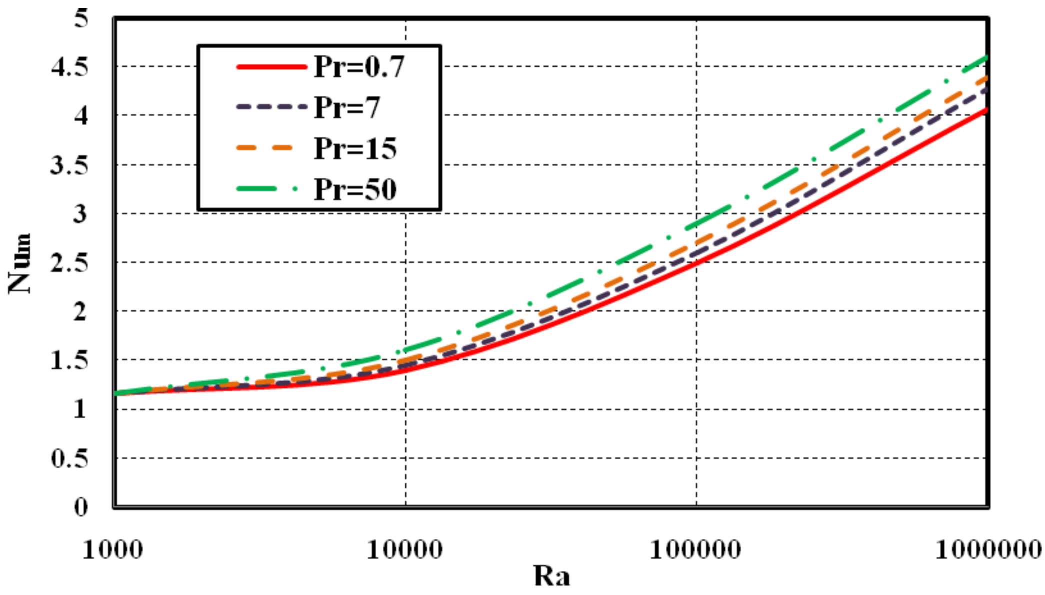

Figure 4: Variation of mean Nusselt number with Ra number for different Pr numbers

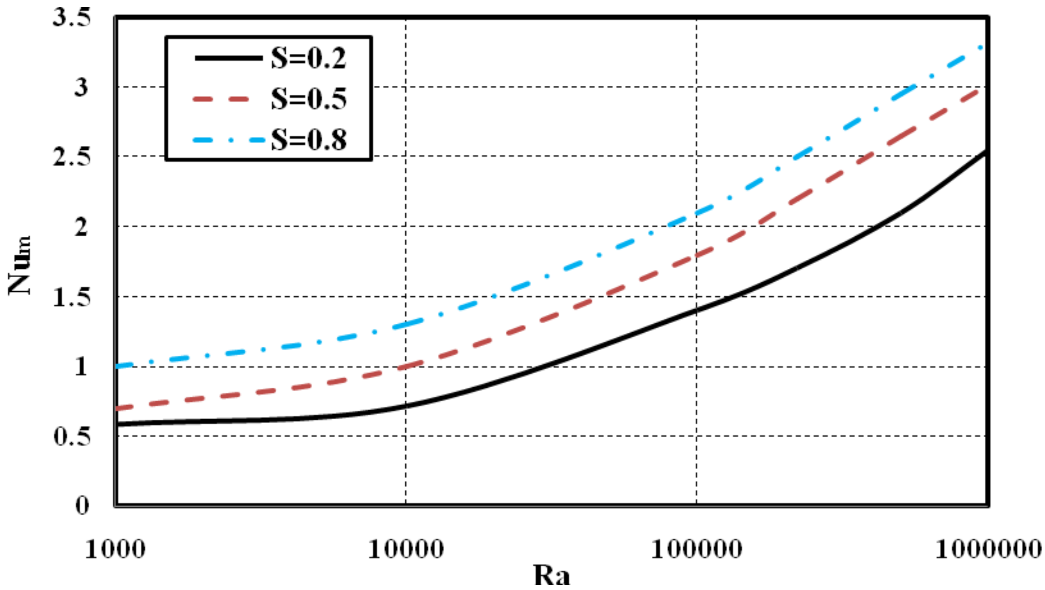

Figure 5: Variation of mean Nusselt number with Ra number for different Heater location

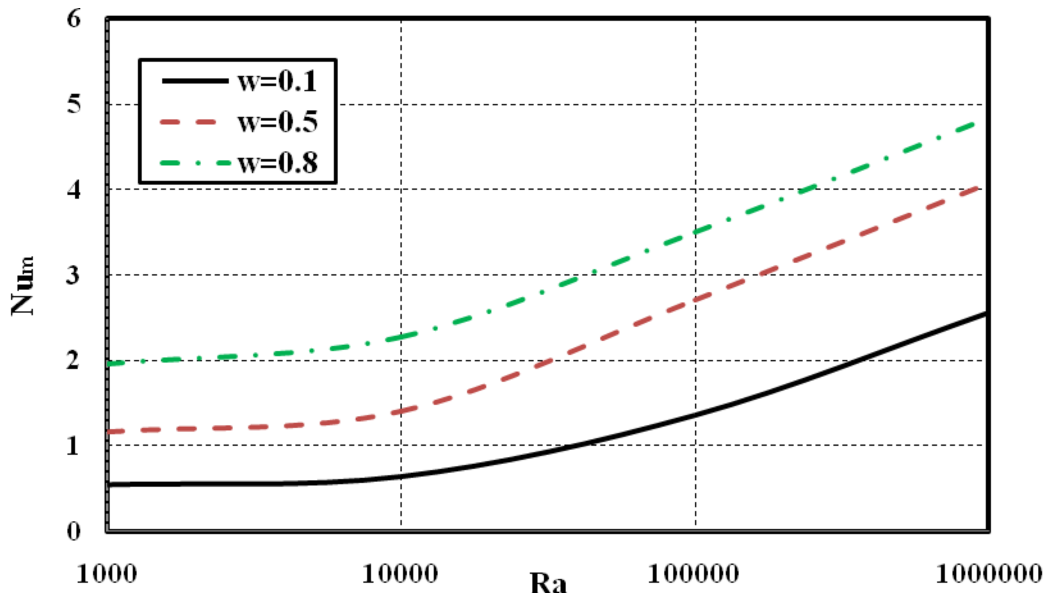

Figure 6. Variation of mean Nusselt number with Ra number for different heater length

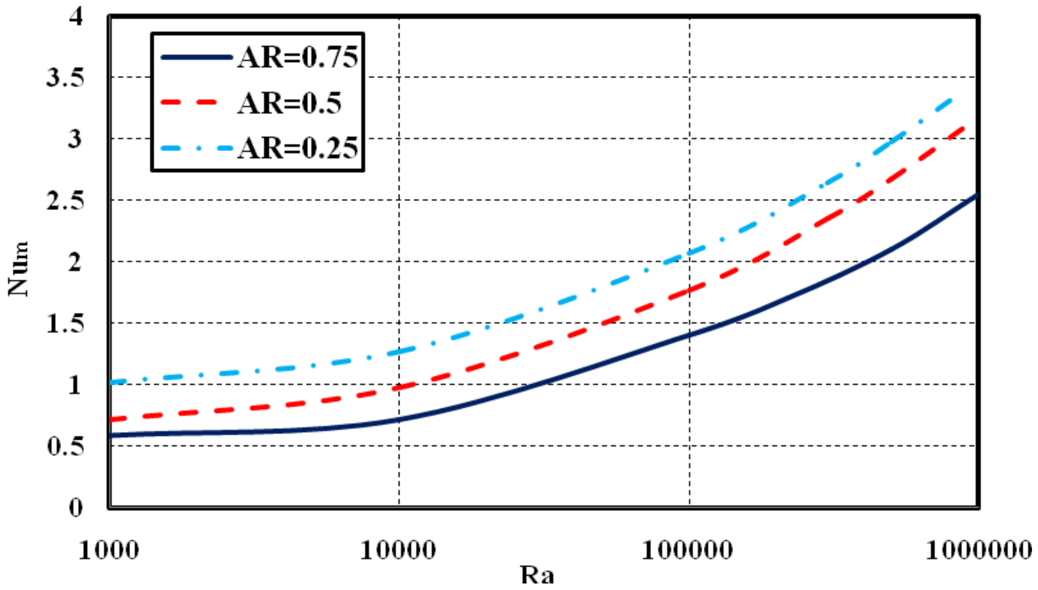

Figure 7. Variation of mean Nusselt number with Ra number for different aspect ratio

Conclusions

In this paper, the effects of different parameters including Pr, location and length of heater and aspect ratio on natural convection heat transfer in right angled triangular enclosure, which is heated from below, are investigated, numerically. Governing equations of natural convection are solved through the finite volume approach, in which buoyancy is modeled via the Boussinesq approximation. Results of the present study are as follows:

- By increasing the Ra, the strength of convection heat transfer increases and consequently, heat transfer rate is enhances.
- Heat transfer rate is increased by a reduction in aspect ratio of the enclosure, which is due to shorter distance between cold and hot wall.
- Moving the heater toward the inclined wall, will enhance the heat transfer rate.

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